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No. 899

COLUMN STRENGTH OF MAGNESIUM ALLOY AM-57S

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# NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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## COLUMN STRENGTH OF MAGNESIUM ALLOY AM-57S

By M. Holt

### SUMMARY

Tests were made to determine the column strength of extruded magnesium alloy AM-57S. Column specimens were tested with round ends and with flat ends. It was found that the compressive properties should be used in computations for column strengths rather than the tensile properties because the compressive yield strength was approximately one-half the tensile yield strength. A formula for the column strength of magnesium alloy AM-57S, based on the test results, is given herein.

### INTRODUCTION

Inquiries have been received for information on the column strength of magnesium alloys, particularly that of AM-57S. Since there were no test data available for verifying the computed curves of column strength for the various alloys, the investigation described herein was undertaken in order to determine the column strength of extruded magnesium alloy AM-57S.

### MATERIAL AND SPECIMENS

The material used in this investigation was magnesium alloy AM-57S having the following nominal chemical composition:

	percent
Aluminum	6.5
Manganese	.2 minimum
Zinc	.8 maximum
Magnesium	rest

The material was furnished in the form of extruded angle ( $2\frac{1}{2}$  by  $2\frac{1}{2}$  by  $\frac{1}{4}$  in.) in the "as-extruded" condition. The seven pieces furnished were cut into specimens as indicated in figure 1. The letter in the specimen number indicates the type of test to be made on the piece. The letter C designates a compressive specimen used to determine the compressive properties of the material. The specimen is a short piece of the full section with the length such that the slenderness ratio of the specimen is 10. The letter T designates a tensile specimen used to determine the tensile properties of the material. Standard flat tensile specimens (reference 1, fig. 2)  $\frac{1}{2}$  inch wide were cut from one leg of the angle. The letter R indicates a column specimen tested with the condition of round ends, and the letter F indicates a column specimen tested with the condition of flat ends. All the column specimens were lengths of the full section.

The tensile properties of the material as determined by the standard tensile test are given in table I. These values are a little less than those considered typical (see reference 2) for this material and indicate a range of about 10 percent in the values of yield strength (offset = 0.2 percent). The stress-strain relations were obtained with a Templin autographic extensometer (reference 3).

The compressive yield strengths (offset = 0.2 percent) of the various pieces of material as determined by testing the compressive specimens between the fixed heads of the testing machine are also shown in table I. These values are considerably lower than those considered typical for the material. The relations between stress and strain from which these values of yield strength were determined were obtained by measuring the relative movement of the heads of the testing machine with dial gages at the four corners of the bearing heads. The yielding of the material at stresses near the yield strength occurred by short quick jerks accompanied by chattering sounds. It is known that stress-strain relations determined in this way do not give accurate stress-strain curves, but the curves have the same characteristics as the correct stress-strain curves; that is, they indicate correctly the yield strength and the general shape of the curve. This type of curve has been found satisfactory for use with aluminum alloys and, in view of the very flat curve obtained for magnesium alloy AM-57S in the region of the permanent set used to define the yield strength, this type of curve should be as satisfactory for determining the yield strengths

as more precise stress-strain relations. Figure 2 shows the stress-shortening curve for specimen 30, which is typical of the curves for the group of C specimens. The measured strains were multiplied by a common factor so that the initial slope would equal the generally accepted value of the modulus of elasticity, 6,500,000 pounds per square inch.

The stress-strain curves for both tension and compression indicate rather low values of proportional limit, between 4000 and 6000 pounds per square inch. The compressive yield strengths are only about one-half as great as the tensile yield strengths. Tensile stress-strain curves are not included.

The ends of the column specimens were finished flat and parallel by turning the specimens on an arbor in a lathe. The specimens are further described in table II. The areas were calculated from the weight and length of the specimens and the nominal specific gravity of the material, which is 0.0647 pound per cubic inch. The crookedness was measured by inserting thickness gages between the specimen and a surface plate. Specimen 8F showed the greatest crookedness, with a ratio of length  $L$  to crookedness  $e$  of 1360:1.

It should be pointed out in connection with this investigation using AM-57S alloy that this alloy has been found under some conditions to be susceptible to stress-corrosion cracking. If this alloy is exposed to a corrosive medium under conditions in which the exposed surfaces are subjected to steady tensile stresses greater than about one-quarter of the yield strength, fracture may occur in a time short enough to render the metal structurally unsatisfactory. Protection by painting will prolong the life of the metal but will not entirely prevent cracking where conditions are severe.

High steady residual tensile stresses left by welding, severe cold-forming operations, faulty assembly of misaligned parts, or pressed-in bushings appear to be the most serious in producing stress-corrosion cracking. The lower stresses produced by normal service loads, particularly by intermittent service loadings, do not appear to have any appreciable influence on the occurrence of stress-corrosion cracking, especially where the corrosive conditions are not severe. Therefore, alloy AM-57S will probably

be entirely satisfactory for applications where "locked-up" stresses are not present or are held to a value less than about one-quarter of the yield strength. Experience has shown that this alloy has been satisfactory in many applications.

#### METHOD OF COLUMN TESTING

The specimens marked "R" were tested as columns with round ends. The special ball-bearing spherical heads were used with the 30,000 pound setup of an Amsler testing machine of 300,000-pound capacity. These heads are known to have a low resistance to tipping. The specimens were placed on the heads as centrally as possible. The relative vertical movement of the heads was measured at the four corners; and, unless the four movements were practically the same for the first few increments of load, the specimen was shifted on the heads until equal movements were obtained. This procedure insured an axial application of the load. The load was applied in increments and the stress-shortening curve determined.

The specimens marked "F" were tested between the fixed heads of the testing machine. This set of heads does not necessarily fix the ends of the specimens since, under large deflections, the specimens could tip on the heads. The stress-shortening relations were also determined for these specimens by measuring the relative movement of the heads.

## RESULTS AND DISCUSSION

The stress-shortening relations of the column specimens are shown in figures 3 and 4. The initial slopes of the curves are all practically equal. Specimen 2R was accidentally loaded to a stress of about 12,000 pounds per square inch before the test. It will be noticed in figure 3 that the stress-shortening curve for this specimen does not indicate a proportional limit as the curves for the other specimens do. The effect of this accidental load was studied during the test of specimen 3R. This specimen was loaded to a stress of 12,000 pounds per square inch and the load-shortening curve determined. The load was then removed and the test repeated. On the second loading, the stress-shortening relation is represented by a straight line parallel to the original slope of the curve from the first loading. The load was again removed and reapplied. The stress-shortening relation for the third loading coincides with that determined for the second loading. The indication is that the proportional limit can be raised by this method of working the metal. The effect on the tensile properties was not determined.

In studying the relation between the properties of the material and the column strength, the stress-strain relations were given consideration. From the stress-deformation data obtained with the dial gages, the relation between the stress and the tangent modulus of elasticity was plotted as shown in figure 5. The values of tangent modulus of elasticity plotted are merely the increments of stress divided by the increments of strain measured by the dial gages and so adjusted that the initial slope of the stress-strain curve was 6,500,000 pounds per square inch.

The stress-modulus relations show a great deal of scatter; it should therefore be appreciated that there would be considerable scatter between the column-test results and a single column curve derived from these data. This scatter is shown in figure 6, in which the column curve was obtained by taking pairs of values of stress and tangent modulus of elasticity from the curve of figure 5 and computing the corresponding values of slenderness ratio from Euler's equation for column strengths

$$\frac{P}{A} = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2} \quad (1)$$

where

- $\frac{P}{A}$  average stress, pounds per square inch
- $E$  modulus of elasticity, pounds per square inch
- $\frac{L}{r}$  slenderness ratio
- $K$  coefficient describing end conditions, taken as 1.00 for round ends and 0.50 for fixed ends

The agreement between the computed column strengths and the actual test values is as good as could be expected from a study of figure 5. For a group of specimens with more nearly uniform stress-modulus relations, the agreement between the test results and the column curve would undoubtedly be better.

Figure 6 shows two other curves also, namely: (1) the curve of equation (1) using a constant value of modulus of elasticity, and (2) the curve of the equation for the column strength of magnesium alloys given in reference 4. The latter equation is a modified Rankine-Ritter formula as follows:

$$\frac{P}{A} = \frac{Y}{1 + Q \left(\frac{L}{R}\right)^2} + \frac{80000}{\left(\frac{L}{r}\right)} \quad (2)$$

where

- $\frac{P}{A}$  column strength, pounds per square inch
- $Y$  yield strength, pounds per square inch
- $Q$  Ritter's constant  $\left(\frac{Y}{C\pi^2 E}\right)$
- $C$  fixation coefficient  $\left(\frac{1}{K^2}\right)$  and the other quantities are as defined in equation (1)

In these equations, the value of modulus of elasticity has been taken equal to the nominal value, 6,500,000 pounds per square inch. It will be seen that, for very long columns, the agreement between the test data and the Euler curve is fair and, for short columns for which the stresses exceed the elastic limit of the material, the discrepancies are on the unsafe side. Equation (2) gives a curve that crosses the trend of the test data. The computed values in the range of intermediate slenderness ratios are too low while the computed values in the range of long columns are too high.

With the great difference between the properties in tension and compression, it would seem important to base computations for column strengths on the compressive properties of the material.

#### TENTATIVE COLUMN FORMULA FOR AM-57S

A study of figure 6 indicates that each of the three column formulas plotted with the data has some disadvantages for general use in design. The Euler curve in which  $E$  is a constant and equal to the nominal modulus of elasticity ( $E = 6,500,000$  lb/sq. in.) tends to give values consistently too high in the range of slenderness ratios (50 to 100) most common in structures. The modified Euler curve in which  $E$  has a changing value equal to the tangent modulus taken from the average stress-modulus diagram is fairly satisfactory and safe but is not convenient for ordinary engineering design purposes. The Rankine-Ritter formula as modified is too conservative in the range of slenderness ratios most frequently used and is unsafe for long columns.

The data from the column tests indicate, however, that a curve of the Rankine-Ritter type with a limiting maximum stress about 95 percent of the compressive yield strength of the material seems to be a satisfactory column curve for AM-57S. In figure 7 the test results have been plotted with a curve of this type in which the values of the constants have been arbitrarily chosen to give a good agreement with the test results. The resulting column formula for AM-57S may be written as follows:

$$\frac{P}{A} = \frac{48000}{1 + 0.00075 \left( \frac{KL}{r} \right)^2} \quad (3)$$



where

P ultimate column load, pounds

A cross-sectional area, square inches

$\frac{L}{r}$  and K are defined in equation (1), and the value of  $P/A$  has a maximum value equal to 95 percent of the compressive yield strength of the material

This formula agrees reasonably well with the test results, is fairly conservative, and has the advantage of being very simple to apply. A suitable factor of safety, of course, must be applied when determining the allowable column stress in design.

It should be appreciated in using equation (3) that it is based on results of tests which are restricted to one lot of magnesium alloy AM-57S. There is no evidence to indicate how generally this formula may be applied to other alloys. For aluminum alloys, it has been found that a single basic type of column formula can be applied with reasonable accuracy to all the various alloys simply by so changing the constants that they bear a certain relation to the compressive yield strength of the material. It is reasonable to believe that this same condition might hold in the case of magnesium alloys.

Equation (3) can be written in the general form

$$\frac{P}{A} = \frac{B}{1 + D \left( \frac{KL}{r} \right)^2}$$

where

B original ordinate of the curve, pounds per square inch

D  $\frac{B}{\pi^2 E}$ ,  $\frac{P}{A}$  has a maximum value equal to x percent of the yield strength

and the other terms are as previously defined. Undoubtedly, a relation exists between the compressive yield strength

and the values of B and X which might be established from test data on additional magnesium alloys

### CONCLUSIONS

The following conclusions concerning magnesium alloy AM-57S seem justified by the foregoing data and discussion:

1. The compressive yield strength of the lot of material tested is approximately one-half the tensile yield strength; therefore, the compressive properties rather than the tensile properties should be used in computations for column strengths.
2. The compressive yield strength can be satisfactorily obtained from the stress-shortening curve determined by measuring the relative movement of the heads of the testing machine. This conclusion agrees with results of previous work on aluminum alloys.
3. The use of the tangent modulus in the Euler column formula gives a curve that agrees fairly well with the column strengths developed.
4. A tentative column formula for magnesium alloy AM-57S, based on the test results given herein, is as follows:

$$\frac{P}{A} = \frac{48000}{1 + 0.00075 \left( \frac{KL}{r} \right)^2} \quad (3)$$

where

P ultimate column load, pounds

A cross-sectional area, square inches

$\frac{L}{r}$  slenderness ratio

K coefficient describing end conditions, taken as 1.00 for round ends and as 0.50 for flat ends

and  $P/A$  has a maximum value equal to 95 percent of the compressive yield strength of the material. This formula fits the test results closely enough that it may be considered satisfactory for ordinary engineering purposes. A suitable factor of safety must be applied to this formula when determining allowable column stresses in design.

Aluminum Research Laboratories,  
Aluminum Company of America,  
New Kensington, Pa., February 4, 1943.

#### REFERENCES

1. Anon.: Tentative Methods of Tension Testing of Metallic Materials. 1940 Supplement to A.S.T.M. Standards, pt. I, Metals. (E 8-40T). A.S.T.M. (Philadelphia), pp. 454-463.
2. Anon.: Properties of Mazlo Magnesium Products. Am. Magnesium Corp., 1941.
3. Templin, R. L.: An Automatic Autographic Extensometer for Use in Tension Tests of Materials. A.S.T.M. Proc., vol. 32, pt. II, 1932, pp. 783-792.
4. Winston, A. W.: Magnesium Alloys and Their Structural Application. Structural Application of Steel and Light-Weight Alloys, Symposium. A.S.C.E. Proc., vol. 62, pt. 1, nos. 8 and 10, Oct. 1936, pp. 1125-1340.

TABLE I.— MECHANICAL PROPERTIES OF MAGNESIUM ALLOY AM-57S

[Extruded angle,  $2\frac{1}{2}$  by  $2\frac{1}{2}$  by  $1/4$  in.]

Specimen	Tensile strength (lb/sq in.)	Tensile yield strength (offset = 0.2 percent) (lb/sq in.)	Elongation in 2 in. (percent)	Compressive yield strength (offset = 0.2 percent) (lb/sq in.)
1	42,700	31,700	12.5	16,000
2	41,290	28,100	<sup>a</sup> 12.0	14,300
3	42,550	29,700	12.0	15,000
4	42,180	29,800	11.0	15,300
5	42,620	28,500	<sup>a</sup> 12.0	15,600
6	42,090	28,300	11.5	15,100
7	43,200	30,600	15.0	15,300
<sup>b</sup> Typical	44,000	30,000	14.0	20,000

<sup>a</sup>Broke outside middle third.<sup>b</sup>See reference 2.

TABLE II.- DESCRIPTION OF COLUMN SPECIMENS OF MAGNESIUM ALLOY AM-57S AND RESULTS OF TESTS

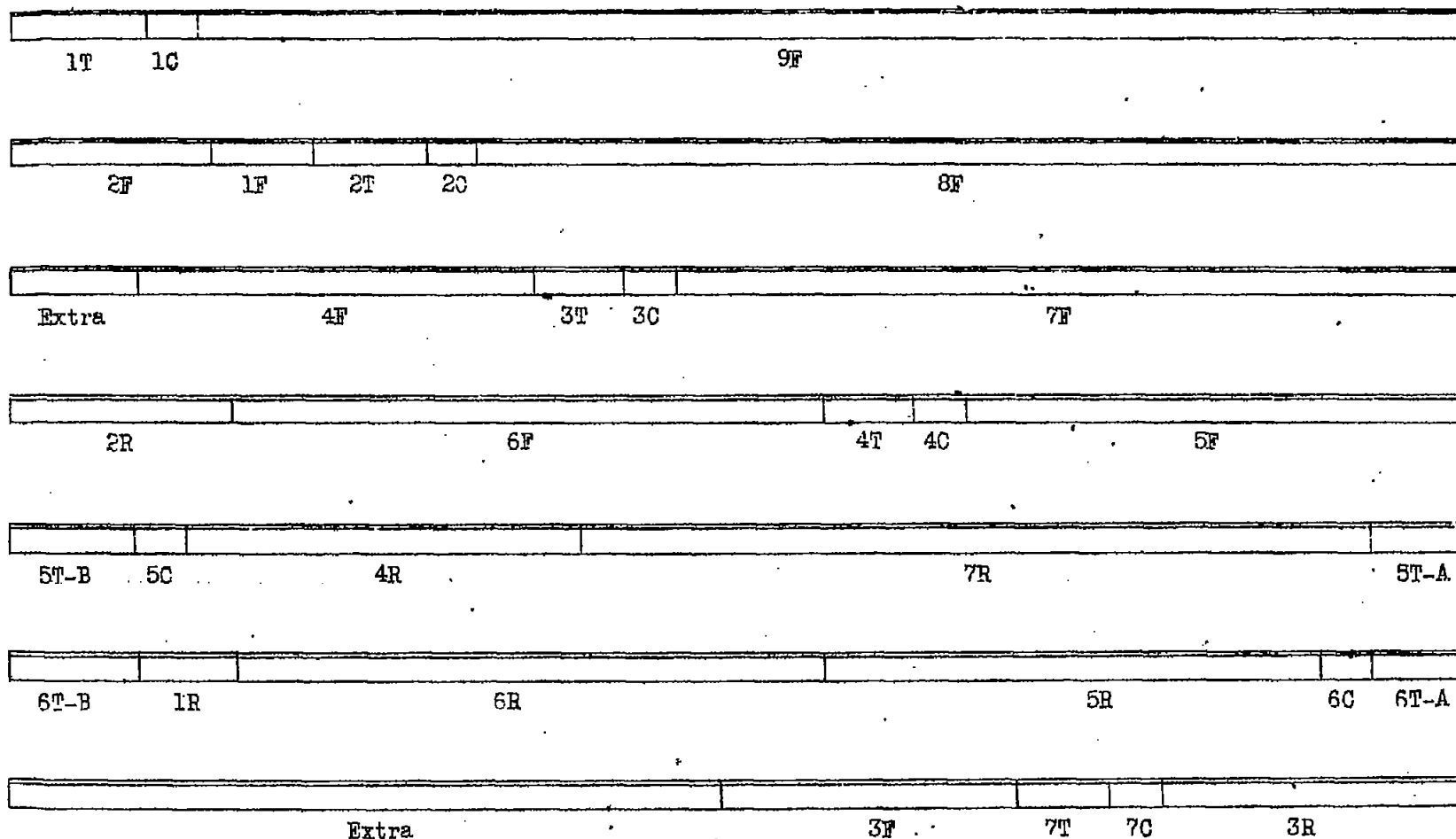
[Extruded angle,  $2\frac{1}{2}$  by  $2\frac{1}{2}$  by  $1/4$  in.]

Specimen (1)	Length, L (in.)	Slenderness ratio	Crookedness e (in.) (2)	Initial curvature	Weight (lb)	Area, A (sq in.) (3)	Max. load, P (lb)	Column strength, $\frac{P}{A}$ (lb/sq in.)
1R	9.93	20	0	Straight	0.776	1.21	17,450	14,420
2R	19.65	40	.004	C-curve	1.536	1.21	17,750	14,670
3R	29.20	60	.004	C-curve	2.266	1.20	16,800	14,000
4R	39.30	80	.026	C-curve	3.063	1.21	10,150	8,390
5R	49.05	100	.011	C-curve	3.827	1.21	7,550	6,240
6R	58.95	120	.006	C-curve	4.600	1.21	5,890	4,870
7R	78.55	160	.006	S-curve	6.108	1.20	3,000	2,500
1F	9.92	20	0	Straight	0.777	1.21	18,250	15,080
2F	19.65	40	0	Straight	1.529	1.20	17,460	14,550
3F	29.50	60	.003	C-curve	2.293	1.20	18,170	15,140
4F	39.30	80	.006	C-curve	3.052	1.20	17,350	14,460
5F	49.05	100	.009	C-curve	3.818	1.20	18,260	15,220
6F	58.95	120	.012	S-curve	4.580	1.20	14,900	12,420
7F	78.55	160	.033	C-curve	6.110	1.20	9,120	7,600
8F	98.10	200	.072	C-curve	7.628	1.20	5,850	4,875
9F	126.1	257	.010	C-curve	9.730	1.19	3,580	3,010

<sup>1</sup>R designates specimens tested as columns with round ends (ball-bearing spherical seats); F, specimens tested as columns with flat ends (fixed heads).

<sup>2</sup>Crookedness as measured by inserting thickness gages between specimen and a surface plate.

<sup>3</sup>Calculated from weight and length of specimen and nominal specific gravity of material (0.0647 lb/cu in.).



T tensile specimen  
C compressive specimen

R column specimen tested with round ends  
F column specimen tested with flat ends

Figure 1.- Locations of specimens in pieces of material furnished. Magnesium alloy AM-57S; extruded angle, 2-1/2 by 2-1/2 by 1/4 inches.

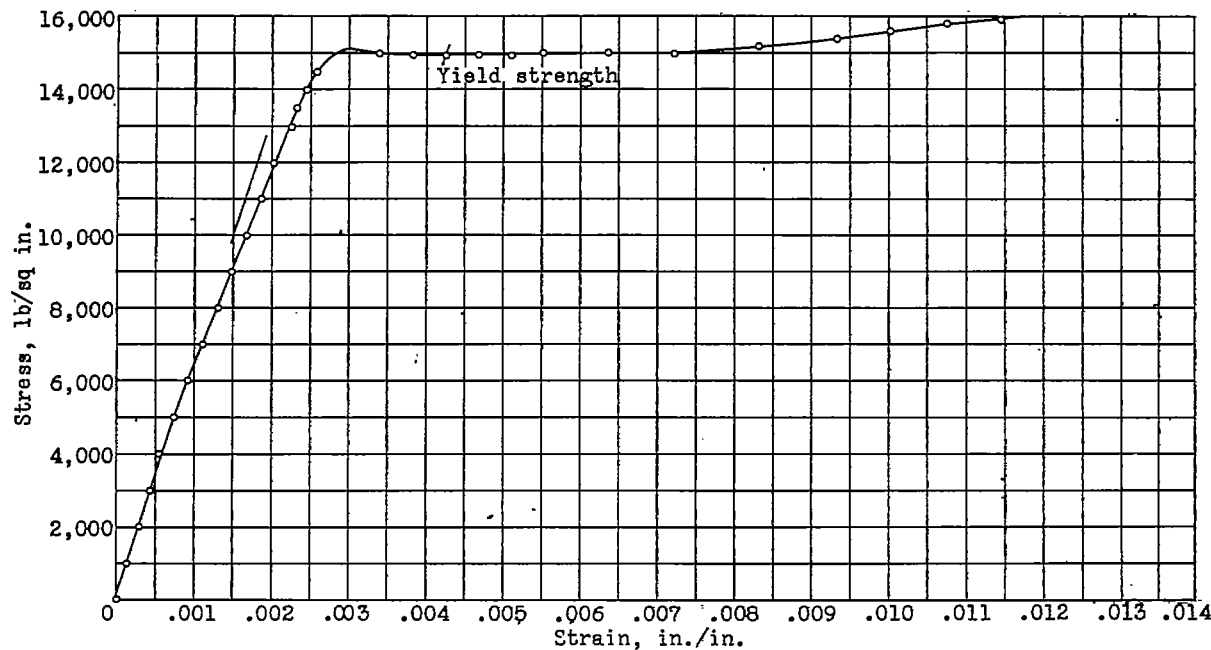
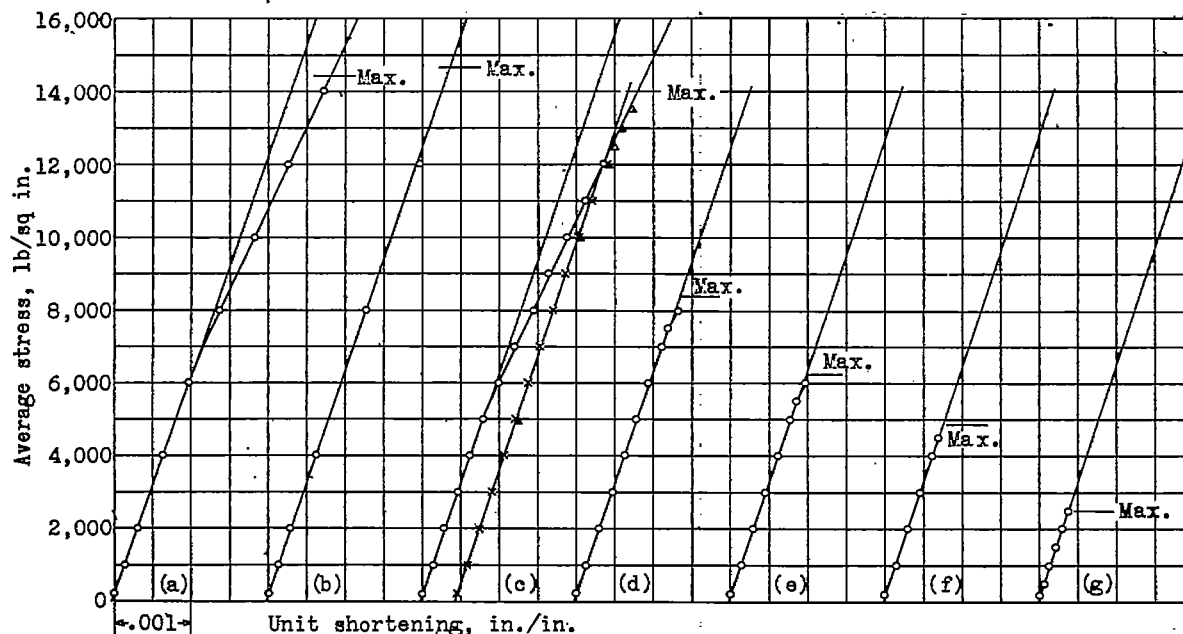


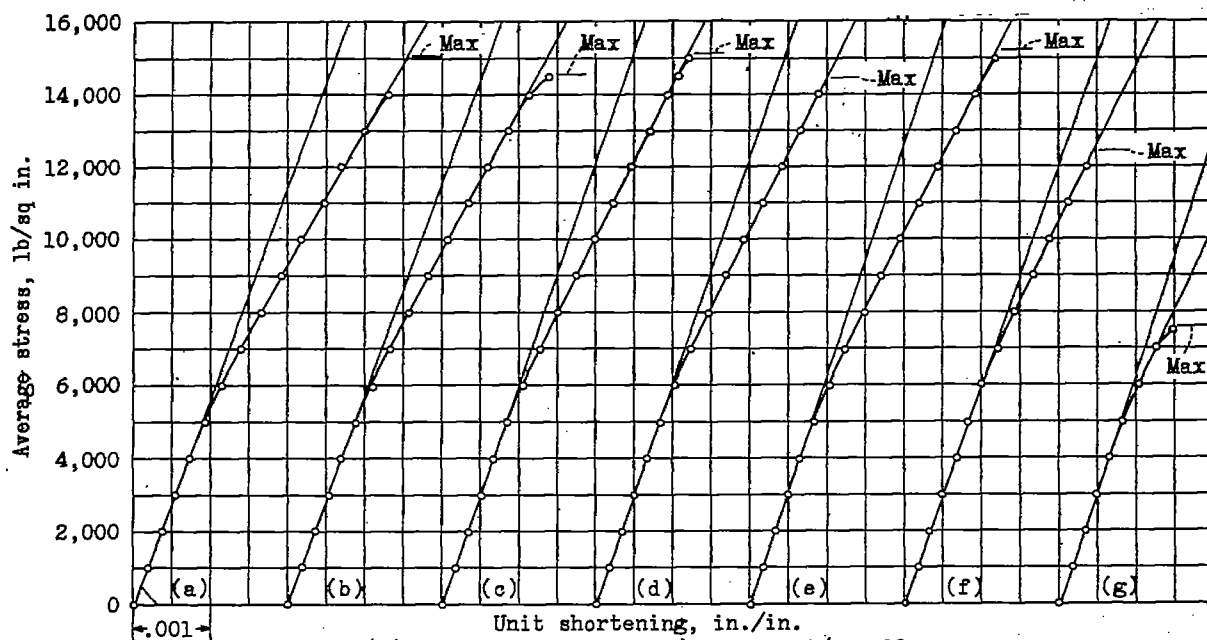
Figure 2.- Compressive stress-strain curve for specimen 3C. Length of specimen, 5.0 inches; area, 1.20 square inches;  $L/r$ , 10. Relative movement of heads of testing machine interpreted as strains.



(1 block = 10 divisions on 1/50 Engr. scale)

(a) Specimen 1R;  $L$ , 9.93 inches;  $L/r$ , 20. (b) Specimen 2R, which was accidentally loaded to about 12,000 pounds per square inch before testing;  $L$ , 19.65 inches;  $L/r$ , 40. (c) Specimen 3R;  $L$ , 29.20 inches;  $L/r$ , 60. (Loading:  $\circ$  first;  $\times$  second;  $\Delta$  third.) (d) Specimen 4R;  $L$ , 39.30 inches;  $L/r$ , 80. (e) Specimen 5R;  $L$ , 49.05 inches;  $L/r$ , 100. (f) Specimen 6R;  $L$ , 58.95 inches;  $L/r$ , 120. (g) Specimen 7R;  $L$ , 78.55 inches;  $L/r$ , 160.

Figure 3.- Compressive stress-shortening curves for specimens tested as columns with round ends. Shortening determined by measuring the relative vertical movement of the heads of the testing machine.



- (a) Specimen 1F; L, 9.92 inches; L/r, 20.  
 (b) Specimen 2F; L, 19.65 inches; L/r, 40.  
 (c) Specimen 3F; L, 29.50 inches; L/r, 60.  
 (d) Specimen 4F; L, 39.30 inches; L/r, 80.  
 (e) Specimen 5F; L, 49.05 inches; L/r, 100.  
 (f) Specimen 6F; L, 58.95 inches; L/r, 120.  
 (g) Specimen 7F; L, 78.55 inches; L/r, 160.

Figure 4.- Compressive stress-shortening curves for specimens tested as columns with flat ends. Shortening determined by measuring the relative vertical movement of the heads of the testing machine.

(1 block = 10/50\*)

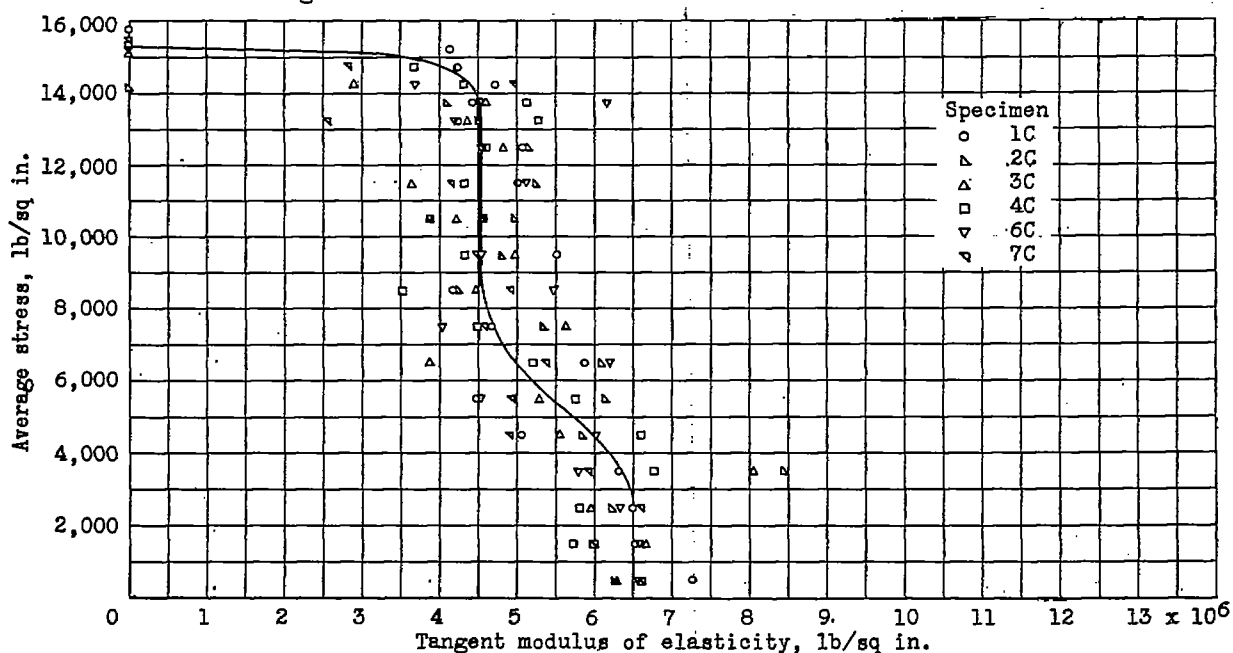


Figure 5.- Stress against tangent modulus of elasticity, obtained as the increment of stress divided by the increment of strain. Length of specimen, 5.0 inches; L/r, 10.



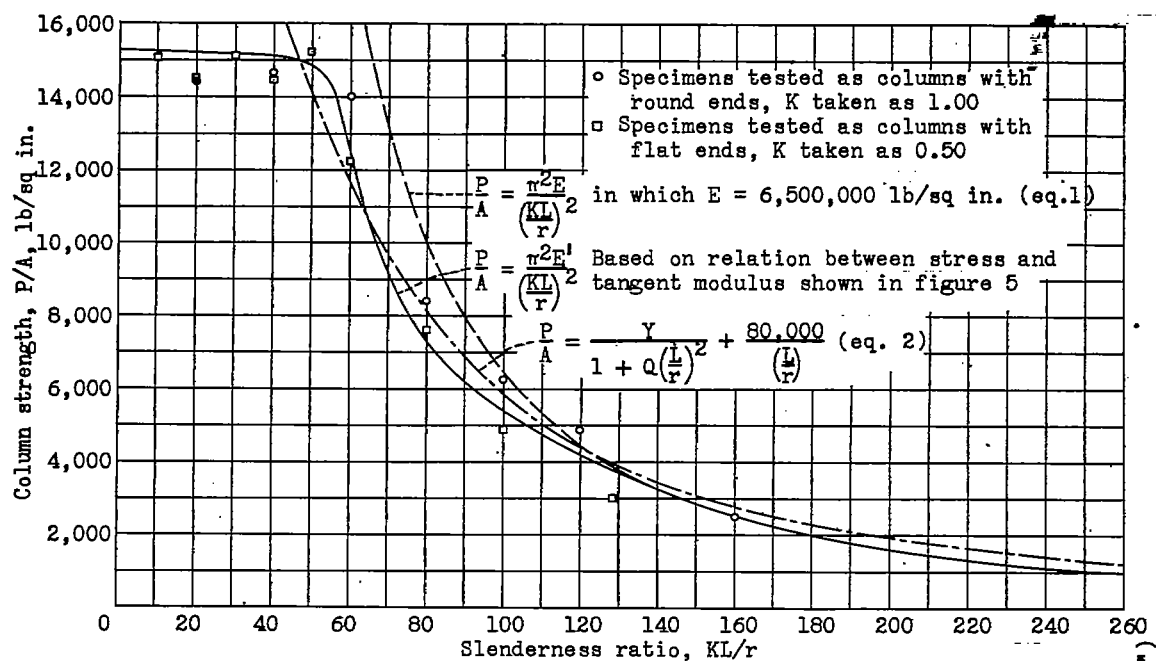


Figure 6.- Column strength of magnesium alloy AM-57S.

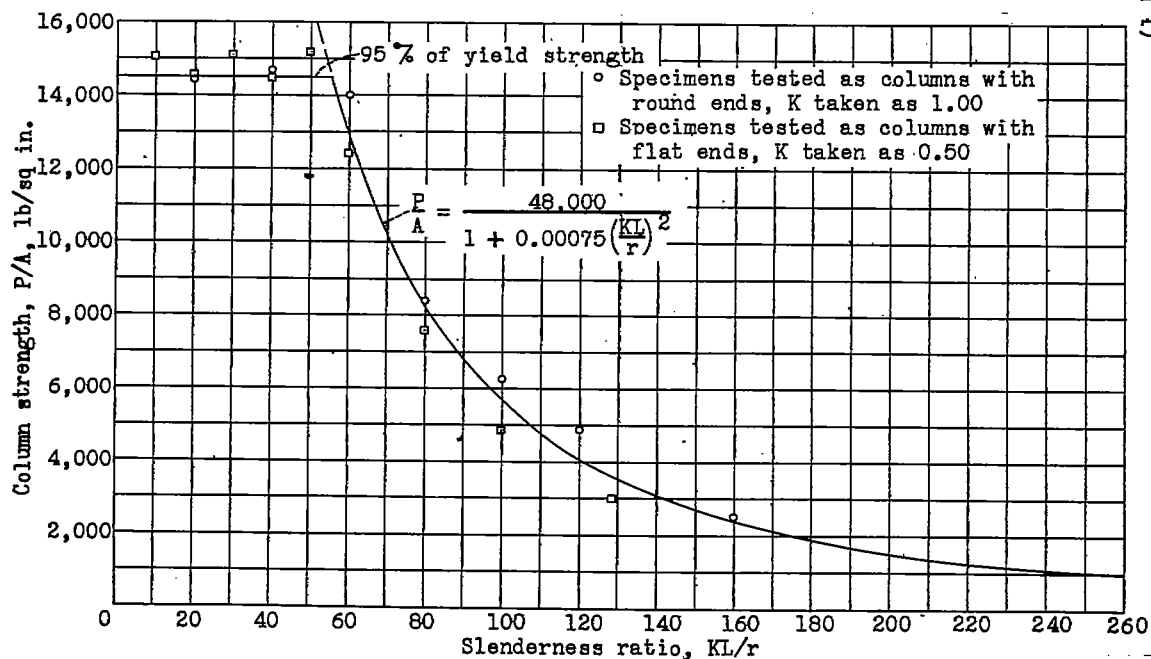


Figure 7.- Column strength of magnesium alloy AM-57S.